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**TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371****US57,0410-WO**

U.S. APPLICATION NO. (If known, see 37 CFR 1.5)

10/088723

INTERNATIONAL APPLICATION NO.

PCT/GB00/04129

INTERNATIONAL FILING DATE

26 October 2000 (26.10.00)

PRIORITY DATE CLAIMED

27 October 1999 (27.10.99)TITLE OF INVENTION **DEPOSITION MONITORING SYSTEM**

APPLICANT(S) FOR DO/EO/US

SCHLUMBERGER TECHNOLOGY CORPORATION

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International application as filed (35 U.S.C. 371(c)(2))
 - a. ☐ is attached hereto (required only if not communicated by the International Bureau).
 - b. ☒ has been communicated by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
 - a. ☐ is attached hereto.
 - b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3)).
 - a. ☐ are attached hereto (required only if not communicated by the International Bureau).
 - b. ☐ have been communicated by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☒ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ An English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 20 below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☐ A **FIRST** preliminary amendment.
14. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
15. ☐ A substitute specification.
16. ☐ A change of power of attorney and/or address letter.
17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821-1.825.
18. ☒ A second copy of the published international application under 35 U.S.C. 154(d)(4). (**WO 01/31329 A1**)
19. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. ☒ Other items or information:

- Form PCT/IB/308 Notice Informing the Applicant of the Communication of the International Application to the Designated Offices

U.S. APPLICATION NO. (if known, see 37 CFR 1.5) <div style="font-size: 24pt; font-weight: bold;">107088723</div>	INTERNATIONAL APPLICATION NO <div style="font-weight: bold;">PCT/GB00/04129</div>	ATTORNEY'S DOCKET NUMBER <div style="font-weight: bold;">US57.0410-WO</div>
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21. <input checked="" type="checkbox"/> The following fees are submitted: BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)): Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO \$1040.00 International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO..... \$890.00 International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$740.00 International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4)..... \$710.00 International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4)..... \$100.00 <div style="text-align: center;">ENTER APPROPRIATE BASIC FEE AMOUNT =</div>	<div style="border: 1px solid black; padding: 2px;"> CALCULATIONS PTO USE ONLY </div>
Surcharge of \$130.00 for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input checked="" type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	<div style="border: 1px solid black; padding: 2px;"> <div style="display: flex; justify-content: space-between;"> \$890.00 </div> <div style="display: flex; justify-content: space-between;"> \$130.00 </div> </div>

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	26 - 20 =	6	x \$18.00	\$108.00	
Independent claims	2 - 3 =	0	x \$84.00	\$	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ \$280.00	\$	
TOTAL OF ABOVE CALCULATIONS =				\$1128.00	
<input type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.				\$	
SUBTOTAL =				\$	
Processing fee of \$130.00 for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				\$	
TOTAL NATIONAL FEE =				\$1128.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property +				\$	
TOTAL FEES ENCLOSED =				\$	
				Amount to be refunded:	\$
				charged	\$1128.00

a. ☐ A check in the amount of \$_____ to cover the above fees is enclosed.

b. ☒ Please charge my Deposit Account No. **19-0615** in the amount of **\$1128.00** to cover the above fees.
 A duplicate copy of this sheet is enclosed.

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 overpayment to Deposit Account No. **19-0615**. A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card
 information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

**NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR
 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.**

SEND ALL CORRESPONDENCE TO:

Intellectual Property Law Department
 Schlumberger Doll Research
 36 Old Quarry Road
 Ridgefield, CT 06877-4108

SIGNATURE

 William B. Batzer
 NAME

37,088

 REGISTRATION NUMBER

10084723 10/088723

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PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of)	
COUET et al..)	
Appl. No.: To be Assigned)	Group Art Unit:
Int'l Appl No.: PCT/GB00/01429)	
Filed: 19 March 2002)	Examiner:
Int'l Filing Date: 26 October 2000)	
For: DEPOSITION MONITORING SYSTEM)	Docket N°: US57.0410-WO

**EXPRESS MAIL CERTIFICATE
UNDER 37 CFR §1.10**

Assistant Commissioner for Patents
Box New Patent Application
Washington, D.C. 20231


Sir:

Express Mail Label Number: EV 060666799 US

Date of Deposit: 3/19/2002

I hereby certify that the attached US national patent application and fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR §1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Box New Patent Application, Washington, D.C. 20231.

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(Print Name)


K L O S S

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11/p/b

- 1 -

Deposition Monitoring System

This invention relates to apparatus and methods for monitoring solid deposits of material on tubing, conduits and other
5 installations. Particularly, the invention relates to such apparatus and methods for sensing and removing material deposited by fluid from hydrocarbon wells.

BACKGROUND OF THE INVENTION

10

The formation of both organic and inorganic deposits in the near wellbore region of producing formations and on the tubing of a producing hydrocarbon well can be a major and costly problem. See, e.g. Allen, T.O. and Roberts, A.P., *Production Operations*,
15 Vol. 2, 2nd edition, pp. 11-19 and 171-181, OGCI, Tulsa, Ok. (1982); Cowan, J.C and Weintritt, D.J., *Water-formed Scale Deposits*, Gulf Publishing Co., Houston (1976). The deposits can seriously impede the productivity of wells by reducing the near wellbore permeability of producing formations and progressively
20 restrict the diameter of the tubing.

The formation of inorganic deposits, or scale, is caused by the precipitation of inorganic salts from produced water. Calcium carbonate scale is usually formed by the change in the pressure
25 and temperature of the produced water in the near wellbore and in the production tubing. Barium, strontium and calcium sulphate scales are usually formed by the mixing of formation water and seawater injected into producing wells; the high concentration of sulphate in seawater mixes with the high concentrations of
30 divalent cations in formation waters with the resulting precipitation of the sulphate salts. The formation of scale may be partly prevented by water shut-off treatments and the use of scale inhibitors. Once formed, scale can be removed only with some difficulty; calcium carbonate scale can be dissolved by
35 mineral acids and barite scale can be removed by milling or

scale dissolvers such as EDTA. See, e.g. Putnis, A, Putnis, C.V. and Paul, J.M., "The efficiency of a DTPA-based solvent in the dissolution of barium sulfate scale deposits", *SPE International Symp. Oilfield Chemistry*, San Antonio, Texas, February 1995, SPE 29094. In extreme cases the production tubing must be removed and replaced, although the presence of radioactive scale (due to the presence of radium salts) can make scale disposal an environmental issue.

- 10 The production of hydrocarbons frequently causes the precipitation of organic precipitates such as paraffin waxes and asphaltenes. These organic precipitates are caused by changes in the pressure and temperature of the produced fluids in the near wellbore. The precipitates can be removed with solvent washes, 15 although the disposal of the solvent after cleaning represents an increasing environmental problem.

The solubility of various inorganic and organic species can be predicted from thermodynamic models of the electrolyte solutions or hydrocarbons. See, e.g. Jasinski, R, Taylor, K. and 20 Fletcher, P., "Calcite scaling - North Sea HTHP wells", *SPE Symp. Oilfield Scale*, Aberdeen, January 1999; Calange, S., Ruffier-Meray, V. and Behar, E., "Onset crystallization temperature and deposit amount for waxy crudes: experimental 25 determination and thermodynamic modelling", *SPE International Symp. Oilfield Chemistry*, Houston, Texas, February 1997, SPE 37239. However, thermodynamic models are essentially equilibrium models and they cannot predict any details of the precipitation process such as the location of precipitation, the 30 rate of precipitation or the degree of supersaturation that the fluid can tolerate.

Several patents and papers have described both acoustic and non-acoustic methods for sensing the formation of scale in producing 35 hydrocarbon wells and similar environments. An acoustic method

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for measuring the thickness of metal oxide corrosion products on the inside of boiler tubes has been described. See Lester, S.R., "High frequency ultrasonic technique for measuring oxide scale on the inner surface of boiler tubes", *US Patent*

4,669,310, June 2, 1987. The thickness of oxide scale is determined by the time of flight of an acoustic pulse applied from the external surface of the pipe. The frequency of the acoustic pulse was 50 MHz, which enabled a scale thickness of approximately 0.1 mm to be detected. The use of an automated ultrasonic inspection system for determining the thickness of scale formation which has formed on the inside of heat transfer tubes in boilers has been described. See Okabe, Y., Iwamoto, K., Torichigai, M., Kaneko, S., Ichinari, J. and Koizumi, K., "Automated ultrasonic examination system for heat transfer tubes in a boiler", US Patent 4,872,347, October 10, 1989. A rotating transducer was inserted into the tubes and their diameter as a function of location determined by the reflection of sound from the scale-water interface. An acoustic wireline logging tool, Schlumberger's Cement Evaluation Tool (CET), has been used to determine the accumulation of scale on the casing of geothermal wells. See, US Patent No 5,072,388, to O'Sullivan et al. The interfaces between the scale and wellbore fluid and the scale and the casing are determined by the transit time of the acoustic waves, which have a frequency of approximately 0.5 MHz. US Patent 5,092,176 disclosed a method for determining the thickness of scale on the inside of a water pipe by the attenuation of acoustic energy emitted and received by a transducer on the outside of the pipe. The optimum frequency range for the ultrasound was observed to be 3-7 MHz. For example, measurements made using ultrasound below a frequency of 3 MHz gave poor sensitivity to scale thickness and beam spreading was observed to be a problem. An acoustic method of identifying scale types and scale thickness in oil pipelines using the attenuation in the reflected acoustic signal from a tool that is moved through the inside of the pipe has been

described. See, Gunarathne, G.P.P. and Keatch, R.W., "Novel techniques for monitoring and enhancing dissolution of mineral deposits in petroleum pipelines", *SPE Offshore Europe Conference*, Aberdeen, Sept. 1995, SPE 30418 (hereinafter "Gunarathne"); Gunarathne, G.P.P. and Keatch, R.W., "Novel techniques for monitoring and enhancing dissolution of mineral deposits in petroleum pipelines", *Ultrasonics*, **34**, 411-419 (1996) (hereinafter "Gunarathne and Keatch"). The frequency of the ultrasound used was in the range 3.5-5.0 MHz, which allowed the thickness of barium sulphate scale on steel to be measured to an accuracy of ± 0.5 mm.

US Patent 5,661,233 (hereinafter "Spates et al.") disclosed several acoustic-wave devices for determining the deposition of organic precipitates, such as paraffin wax, on to a sensing surface immersed in a petroleum-based fluid. The acoustic measurements were made with devices using various acoustic modes: surface acoustic waves and thickness shear, acoustic plate and flexural plate modes. The devices measured changes in the damping voltage and resonant frequency of the device as the wax precipitate formed, although no details were disclosed regarding the operating frequencies of the acoustic devices or the acoustic power they generated. Spates et al. discussed periodic cleaning of the sensing surface of the acoustic device by heating the surface to melt the paraffin wax. However, the use of acoustic energy to clean the organic precipitates from the acoustic sensor was not disclosed or suggested. Several applications of the measurement of wax accumulation were described, including location of acoustic devices on the sea floor to monitor the production of hydrocarbon from oil wells and guide well treatments. The application of a quartz microbalance to measure simultaneously mass loading and liquid properties has been described. See, US Patent 5,201,215; Martin, S.J., Granstaff, V.E. and Frye, G.C., "Characterisation of a quartz crystal microbalance with simultaneous mass and

The application of an on-line quartz crystal microbalance to monitor and control the formation of organic and inorganic precipitates from hydrocarbons and water has been described. See, US Patent 5,734,098 (hereinafter "Kraus et al."). The quartz crystal microbalance consisted of a thickness-shear mode resonator and was described by Kraus et al. as being substantially similar to those disclosed by Granstaff and Martin. Kraus et al. described the use of the thickness-shear mode resonator for the on-line measurement of scaling, corrosion and biofouling in industrial processes. They also described the use of the measurement of deposit formation to determine the treatment required to correct the industrial process and prevent continual deposit formation, e.g., by use of a chemical additive such as an inorganic scale inhibitor. Although Kraus et al. described the use of a thickness-shear mode resonator to monitor deposit formation from hydrocarbons, industrial water and their mixtures (including emulsions), no disclosure or suggestion was made to the operation of these sensors in or near producing hydrocarbon wells, on either a temporary or permanent basis. Additionally, there was no disclosure or suggestion regarding the treatment of producing hydrocarbon wells, for either organic or inorganic deposit formation, on the basis of measurements made by these sensors.

(Musical notation for "The Rose Tree")

The musical score for 'The Rose Tree' is written for voice and piano. The key signature is one flat (B-flat), and the time signature is 4/4. The melody is simple and catchy, with a range of one octave. The piano accompaniment consists of a steady eighth-note bass line and a treble line with chords and single notes. The score includes a key signature change to two flats (B-flat and E-flat) for the final section, which features a more complex piano accompaniment with sixteenth notes in the right hand.

"Nohata and Taguchi"). Although Nohata and Taguchi did not specifically disclose the operating frequency of the quartz crystal, a value of about 5 MHz can be deduced from the measured accumulation rates of 1-20 $\mu\text{g}/\text{cm}^2$ per day.

5

The use of a tuning fork for measuring the deposition of scale in a surface process system has been disclosed. See, US Patent 5,969,235. The accumulation of scale on the tines of the tuning fork causes a shift in the characteristic vibrating frequency of the tuning fork as measured by a suitable electronic device, such as a piezoelectric cell. The change in vibrating frequency of the tuning fork, indicating the deposition of scale, was used to control the addition of scale inhibitor to the process stream.

15

Non-acoustic scale sensing techniques have also been reported. A method of determining the accumulation of scale in petroleum pipelines using a heat transfer sensor has been described. See, US Patent 4,718,774. The scale formed on the external wall of the sensor impeded the loss of heat from a heating element in the sensor to the fluid flowing in the pipeline. The decrease in heat flow was measured by means of a temperature sensor. A wellbore scale monitor that measured the radioactivity of the radium salts precipitated with other alkaline earth metal salts has been described. See, US Patent 4,856,584 (hereinafter "Sneider"). Sneider discloses the use of measurements of scale radioactivity to indicate when and where the placement of scale inhibitor is required. Another scale monitoring technique is disclosed in US Patent 5,038,033; the radioactivity of the scale was detected by a wireline gamma ray detector, correcting for the natural gamma radiation emitted from the surrounding rock formations.

Accurately measured pressure drops over various sections of a
35 reinjection pipeline in a geothermal power plant has been used

A number of published reports have described the application of sonic energy for cleaning producing oil wells and equipment in similar industrial processes. A method of cleaning downhole deposits, such as tar, from producing formations and production tubing was disclosed in US Patent 3,970,146. However, no details were given of the power or frequency of the sound used for wellbore cleaning. A low frequency (20-100 Hz) vibrating device for cleaning deposits on the walls of casing and tubing and in

formations and gravel packs was disclosed in US Patent 4,280,557. The vibrations were generated in the device by an orbiting mass on an unbalanced rotor, which, in turn, produced a whirling vibratory pressure of large amplitude in the fluid in the annulus. US Patent 4,320,528 disclosed a method of removing iron oxide corrosion products and other scaling deposits from the pipes of steam generators using a combination of high power sound and a high-temperature solvent (e.g., sodium EDTA, citric acid and a corrosion inhibitor). The acoustic transducers operated in the frequency range 2-200 kHz and generated an output acoustic power greater than 0.2 W/cm^2 , a value which is above the cavitation threshold of aerated water at ambient pressure and temperature. See, Esche, R., "Untersuchung der Schwingungskavitation in Flüssigkeiten", *Acustica*, 2, AB208-218 (1952); Mason, T.J. and Lorimer, J.P., *Sonochemistry: Theory, Applications and Uses of Ultrasound in Chemistry*, p 31, Ellis Horwood, Chichester, UK (1988). The transducers were located permanently on the outside of the heat exchanger tubes. US Patent 4,444,146 disclosed an ultrasonic method to clean the fouled surfaces of submerged structures, such as the hulls of ships. The ultrasonic cleaner consisted of two ultrasonic transducers focussed on a small area of surface to be cleaned. The transducers operated at slightly different frequencies, typically in the range 180-210 kHz; no details were disclosed on the acoustic power required to clean the fouled surfaces. UK Patent Application 2 165 330 A (hereinafter "D'Arcy et al.") disclosed a method of cleaning underwater structures to depths of up to 1000 metres using focussed ultrasound in the frequency range 40-100 kHz. The ultrasound was generated and focussed using an array of transducers located on the concave surface of a spherical cap. The density of acoustic power at the focal point of the array of transducers was stated to be about 500 W/cm^2 , a value that is approximately 3 orders of magnitude above the cavitation threshold of water at ambient pressure. D'Arcy et al. suggested the high power acoustic array could be used to

clean the base of oil production platforms. US Patent 5,184,678 disclosed the design of a high power acoustic logging tool to stimulate fluid production from oil wells. The acoustic power was provided by pulsed magnetostrictive transducers operating in
5 the frequency range 5-30 kHz and emitting an acoustic power density of up to 1 W/cm^2 . The tool was designed to give a stand-off from the treated formation of $0.2-0.5\lambda$, where λ is the wavelength of the sound in the borehole fluid. The treated formations were exposed to the acoustic power for periods of 5-
10 60 minutes. According to US Patent 5,184,678, the applied ultrasound reduced the viscosity of the fluid in permeable formations and fluidised the particulate matter, thus facilitating its removal.

15 It has been shown that ultrasound applied at a frequency of 10 kHz could remove asphaltene deposits from a sand pack saturated with both water and kerosene at ambient pressure. See, Gollapdi, U.K., Bang, S.S. and Islam, M.R., "Ultrasonic treatment for removal of asphaltene deposits during petroleum
20 production", *SPE International Conf. Formation Damage Control*, Lafayette, Louisiana, February 1994, SPE 27377. Although the acoustic power applied to the sand packs during cleaning was not measured, the ultrasonic transducer could generate a maximum output acoustical power of 250 W. The authors discussed the role
25 of acoustic cavitation in the cleaning process and acoustic cavitation was undoubtedly achieved at the power settings reported. The asphaltene deposits were observed to be removed significantly more efficiently by the ultrasound in kerosene than in water. It has been demonstrated under laboratory
30 conditions that the damage caused to permeable formation by the invasion of clay particles from drilling fluids can be partially removed by the application of high power ultrasound. See, Venkitaraman, A., Roberts, P.M. and Sharma, M.M., "Ultrasonic removal of near-wellbore damage caused by fines and mud solids",
35 *SPE Drilling & Completions*, **10**, 193-197 (1995). Two ultrasonic

use of high power ultrasound to remove the filter cake formed by the drilling fluid during the drilling of a well in order to measure the pressure in permeable formations. The high power ultrasound was generated by a focussing transducer operating in
5 the frequency range 100-500 kHz and capable of operating at a peak input power of up to 1 kW. US Patent 5,727,628 disclosed an ultrasonic tool for cleaning producing wells. The wireline-deployable tool consisted of an array of magnetostrictive transducers operating in the frequency range 18-25 kHz
10 (preferably at 20 kHz) and emitting an acoustic power density in the range 8-12 W/cm². The tool was also equipped with a pump to remove the debris of the fouling deposits disaggregated by the ultrasonic tool. US Patent 5,735,226 disclosed a method to prevent the fouling of ships and other marine structures by the
15 use of ultrasound over the frequency range 20-60 kHz. One demonstration of the technique was the location of a number of ultrasonic transducers on the hull of a ship over a period of 4 months. Over this time period the transducers, which were powered intermittently, gave effective relief from marine
20 fouling. US Patent 5,735,226 revealed no details of the power consumption of the transducers, but one embodiment of the invention consisted of the array being powered by a 9 volt battery. US Patent 5,889,209 disclosed the use of high power ultrasound to prevent biofouling of chemical sensors used in
25 aquatic environments. The ultrasound was generated by a transducer operating in the frequency range 10-100 kHz and yielding a sufficient power density (> 0.1-1 W/cm²) to drive acoustic cavitation. US Patent 5,889,209 disclosed the use of the acoustic cleaning technique to maintain the performance of a
30 dissolved oxygen sensor located in microbiologically active water for seven days. The transducer was located over the range 4-10 mm from the active membrane of the oxygen sensor and activated for a time period of 6-90 seconds over a time interval of 5-120 minutes.

Several papers and patents have reported on the use of high power ultrasound to accelerate the dissolution of scale by chemical scale dissolvers applied in pipelines and producing oil wells. Paul, J.M. and Morris, R.L., "Method for removing alkaline scale", *International Patent Application* WO 93/24199, 9 December, 1993 describes the use of low frequency (1.5-6.5 kHz) sonic energy to accelerate the dissolution of alkaline earth metal scales using scale dissolving solutions (typically containing the chelating agents EDTA or DTPA). Gunarathne, and Gunarathne and Keatch have shown that the application of low-power ultrasound can increase the rate of dissolution of barium sulphate scale using commercially available scale dissolvers; the power density was claimed to be below that required to cavitate the scale dissolving solution.

In conclusion, there appears to be no prior art that teaches or suggests either an acoustic scale sensor or an acoustic cleaning device located permanently or quasi-permanently in a well producing hydrocarbons. There appears to be no prior art of teaches or suggests the concept of a sensor for hydrocarbon wells to monitor the formation of inorganic or organic scales, biofouling or corrosion and initiate a cleaning action. Additionally, there appears to be no prior art that teaches or suggests an on-line deposits monitoring and cleaning device located on the surface facilities of a producing oil well using an ultrasonic transducer operating in its longitudinal mode and coupled to the produced fluids using a coupling material, such as an acoustic horn, to which the deposits adhere.

30 The horn material can be chosen arbitrarily from a large variety
of solid materials. It is however a preferred feature of the
invention to have the horn tip made of a material that matches
the properties of the surrounding material, so as to ensure that
the deposits on the surrounding material are accurately
35 measured.

Installed at the surface on surface facilities or above ground refers to the location out of a wellbore, such as a subsea pipeline or a riser, or surface production facilities, such as water-oil separators, or even non-hydrocarbon related processing facilities.

These and other features of the invention, preferred embodiments and variants thereof, possible applications and advantages will become appreciated and understood by those skilled in the art from the following detailed description and drawings.

DRAWINGS

- FIGs. 1A-D are schematic illustrations of examples of acoustic devices, according to certain embodiments of the invention;
- FIG. 2A shows the resonant frequencies of an acoustic device shown in FIG. 1B as measured by the real part of the admittance in air, water and kerosene;
- FIG. 2B shows an enlarged part of FIG 2B;
- FIG. 3 illustrates the shift of the resonant frequency with increasing scale deposition at a hydrostatic pressure of 272 bar (4000 psi);
- FIG. 4 illustrates the shift of the resonant frequency with increasing wax deposition at ambient pressure;
- FIG. 5 illustrates the shift of the resonant frequency after cleaning the tip of a sensor;

FIG. 6 illustrates the power supply used to remove deposits from a surface exposed to wellbore fluids;

5 FIG. 7 illustrates a downhole installation in accordance with the invention;

FIG. 8 illustrates a sensor installation with self-cleaning equipment in accordance with the invention;

FIGS. 9A,B illustrate further sensor installations with self-cleaning equipment in accordance with the invention; and

15 FIG. 10 shows a schematic sensor adapted to further analyse wellbore deposits.

20 MODE(S) FOR CARRYING OUT THE INVENTION

(I) ACOUSTIC SCALE/DEPOSITS SENSOR

The scale (or deposits) sensor consists of an ultrasonic piezoelectric transducer operating in a longitudinal mode
25 coupled to a suitable metal horn. The resulting ultrasonic device is characterised by a sharp resonant frequency, which can be conveniently determined by the measurement of the admittance (or impedance) spectrum of the device. The resonance frequency of the appropriate longitudinal mode is sensitive to any solid
30 deposit that forms on the tip of the horn and the magnitude of the frequency shift is a measure of the mass loading. These ultrasonic transducers typically operate in the frequency range 10-100 kHz and can deliver high levels of acoustic power, typically in the range 1-500 W, when driven by a high input
35 alternating voltage at its resonant frequency.

FIG. 1 shows schematics of several types of acoustic horn attached to an ultrasonic transducer. The basic elements of the scale deposit sensor 10 are a transducer 11 made of

5 piezoelectric material, a power supply with electrodes 12 to cause oscillations of the transducer, and a horn 13. The horn is made of aluminum. The working surface of the transducer 131, on which the deposition of the scale is sensed, is the tip of the horn. In a downhole and surface installations, the tip 131 (or
10 141, 151, and 161 for the embodiments of Figures 1B, 1C, and 1D respectively) will be exposed to wellbore/production fluids and accumulate deposits.

The resonant frequency of the acoustic device operating in a
15 longitudinal mode is determined by the size of the piezoelectric and the attached horn and the materials from which the piezoelectric and metal horn are constructed. The variants differ in their respective horn design. The horn 13 shown in FIG. 1A has a stepwise tapering. In FIG. 1B, the tapering is
20 smooth with an exponentially reducing diameter of the horn 14. The horn coupled to the ultrasonic piezoelectric transducer is made of aluminium. The resulting device has a sharp resonant frequency in air of 40 kHz nominally and the area of the horn tip was 0.2 cm². In FIG. 1C, the tapering is degenerated to a
25 single step giving the horn 15 a pin-like shape. Other horn shapes can be envisaged, including the case where its thickness is very much less than the wavelength of sound and the horn is a thin layer of material that couples the ultrasonic transducer to the bore hole fluids and their deposits.

30 Further indicated in FIG. 1 is the length of the horn as integer multiple N of half the wavelength ($\lambda/2$) of the acoustic wave generated by the transducer. FIG. 1D shows the case where the

length of the horn 16 is very much less than $\lambda/2$ and the horn tip 161 has the same area as the ultrasonic transducer.

Table 1 shows the resonant frequency of the ultrasonic horns and the widths of the resonance at half peak height shown in FIG. 1A-C. The peak width of the resonance is typically 1-2% of the resonant frequency.

Table 1. Resonant frequencies in air of the ultrasonic transducers shown in FIG. 1A-C.

Transducer type in FIG. 1	Resonant frequency (kHz)	Width of resonance at half peak height (Hz)
A	19.86	21
B	39.04	52
C	54.63	96

FIG. 2 shows the resonant frequency of the acoustic sensor shown in FIG. 1B as measured by the real part of the admittance in Siemens (S). The resonant frequency of the ultrasonic transducer is modified by the nature of the fluid in which it is immersed. FIG. 2 compares the resonant frequency of the ultrasonic transducer immersed in air, water and kerosene. The resonance frequency of the transducer decreases when the metal horn is immersed in a denser fluid and the resonance broadens with more viscous fluids. The fine structure (shown in FIG. 2B) on the admittance spectra measured when the transducer is immersed in water and kerosene at ambient pressure is caused by the attachment of small air bubbles to the horn.

(II) ACOUSTIC SCALE/DEPOSITS CLEANING

The inorganic and organic deposits that accumulate on the tip of the horn can be removed by applying a high alternating voltage to the transducer. The strain produced in the transducer and the attached horn breaks the bond between the horn tip and the deposit and the tip is cleaned. The acoustic deposits sensor can therefore be self-cleaning. The acoustic scale/deposits sensor is also able to clean scale from the surfaces of other components, which are either in close proximity to the tip of the horn or incorporated into it.

The scale was deposited on the tip of a metal horn connected to a 20 kHz ultrasonic transducer. The horn and transducer were housed in the cap of a cell that can be pressurised to 340 bar (5000 psi). The area of the horn tip is 2.87 cm², the average scale thickness is 1.47 mm and the scale density is 4.50 g/cm³. A high voltage was applied to the transducer and the horn was sonicated in a pressure cell at a hydrostatic pressure of 136 bar (2000 psi). All of the inorganic scale was removed from the tip of the horn.

FIG. 5 compares the admittance spectra of the acoustic transducer and metal horn before and after acoustic cleaning at 136 bar (2000 psi). The resonant frequency of the ultrasonic transducer and metal horn changed by 210 Hz after sonication.

The electrical power that is required by the transducer to remove the scale from the tip of the horn can be determined from the input voltage and current. The frequency of the input voltage and current is 19.84 kHz, which compares to a value of 19.81 kHz obtained from the admittance spectrum of the cleaned horn. The scale, which consisted of a deposit with a density of 4.50 g/cm³ and a thickness of 1.47 mm, was removed from the metal horn at a hydrostatic pressure of 136 bar (2000 psi). FIG. 6

- 24 -

shows the input power waveform supplied to the transducer during the cleaning of the scale. The modulus of the time-averaged input electrical power of the waveform shown in FIG. 6 is 20.4 W.

5

(III) SOME APPLICATIONS OF AN ACOUSTIC DEPOSITS SENSOR AND CLEANER

According to the invention a permanent scale/deposits monitor is provided. Ultrasonic transducers, of the type described above, operating over a range of frequencies, typically 10-150 kHz, can be permanently installed in a producing hydrocarbon well to determine the rate of accumulation of scale and other deposits (wax, asphaltene, etc.). The transducers can be deployed at various locations in the well, including surface production facilities such as subsea valves, risers, separators and any associated pipes and conduits, in order to determine the location of scale formation. The transducers can be used to determine the rate of accumulation of scale and other deposits and these measurements can be used to select the appropriate treatment to maintain the productivity of the well, such as the deployment of scale inhibitors or scale dissolvers. The deposits accumulated on the horn attached to the transducer can be cleaned periodically to maintain its sensitivity.

25

According to the invention the apparatus can be used in the maintenance of intelligent completions. More specifically, the ultrasonic sensor can be used to determine the accumulation of scale, wax or asphaltene on critical downhole equipment, such as chokes, valves and the sliding sleeves on intelligent completion systems. The measurements can be used to select an appropriate treatment to maintain the integrity and operation of the equipment, e.g., deployment of a scale dissolver to remove scale from critical components.

35

- 25 -

In FIG. 7 reference is made to an "intelligent" completion system deployed to control the flow of wellbore fluid into a production pipe.

5 FIG. 7 shows a schematic of part of an intelligent completion system. An intelligent completion allows active control of downhole processes such as flow rate measurements and control. A wellbore 70 is shown with a casing 701 installed. At certain locations the casing 701 is perforated by holes 702 to allow
10 wellbore fluid to enter the wellbore. Installed within the wellbore is a production pipe 71 with a slotted section 711. Wellbore fluid enters the production pipe via the slotted section 711. Mounted within the production pipe is a sliding sleeve 712. The sliding sleeve 712 controls the flow of
15 reservoir fluids into the production tubing from a particular section of the well. The flow rate, pressure and temperature of the production fluids are measured by a sensor sub 713 near the slotted section 711 into the tubing. The sliding sleeve 712 is operated by a downhole electrical motor 714 that is powered by
20 means of an electrical cable 721 from the surface 72.

One problem associated with the use of a sliding sleeve is the formation of wellbore deposits, such as inorganic scale or wax, on the sleeve or its track. It is common practice to design the
25 completion hardware such that the electric motor 714 is sufficiently powerful to remove small amounts of scale when the sleeve is moved. However, attempting to remove scale or other deposits by scraping with the sleeve 712 may result in damage to the track and possible jamming. The location of an acoustic
30 scale sensor 715 close to the sliding sleeve 712 will enable the accumulation of deposits on completion hardware to be assessed quantitatively through control equipment 722 located at the surface. Transfer of energy and data signal between control equipment 722 and the sensor 715 is done via wiring 716 run with

the production tubing. If scale accumulation on the sleeve is considered to be above a level at which it can be safely operated, then an external scale removal process may be required (e.g., application of a scale dissolver solution).

5 Alternatively, the control equipment 722 could be used to activate the sleeve periodically or responsive to a threshold amount of deposit as measured by the scale sensor 715. In yet another alternative the control equipment 722 could at least partly be incorporated into the downhole installation. By thus
10 providing a direct feedback control between sleeve and deposit monitor 715, the amount of intervention from the surface can be reduced.

According to the invention, acoustic cleaning of scale and other
15 deposits is provided. The ultrasonic transducer and associated horn can be used to remove scale and other deposits (wax, asphaltene, etc.) from critical components that are used in measurement devices exposed to wellbore/production fluids in the wellbore or on the surface. The components can be part of
20 measurement systems that are either permanently installed in producing hydrocarbon wells or surface facilities or temporarily exposed to the fluids produced by the hydrocarbon well, e.g., on a wireline-deployable tool. Critical components exposed to wellbore fluids that may require cleaning include separation
25 membranes, optical windows and electrical contacts such as electrodes.

FIG. 8 refers to a venturi-type flowmeter having a gamma-ray sensor in its constriction section.

30

It shows a schematic of a gradio-venturi tube 81 located in the tubing 80 of a producing hydrocarbon well. The section of tubing 80 can be located either in a well or on surface facilities. Located within the constriction formed by the
35 venturi 81 is a gamma ray sensor 82. Details of those known

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FIG. 9 shows further examples of the use of an ultrasonic transducer and horn to clean measurement devices that may be deployed in a producing hydrocarbon well or at surface installation monitoring the flow of hydrocarbon from the well.

5

FIG. 9A shows a schematic of an optical window 931 located at the tip of a horn 93 attached to an ultrasonic transducer 91. The optical window 931, which can be made of a suitably resistant material such as diamond or sapphire, can be connected to a source and detector using an optical fibre 95 or other optical conduit such as a light pipe. The optical transmission of the window can be maintained by removing deposits of organic and inorganic scales with ultrasonic cleaning. The accumulation of deposits on the optical window can be determined by either the decreased transmissivity of the window or the change in the admittance spectrum of the transducer 91 and horn 93 assembly. The optical windows can be located either in a producing oil well, on a permanent or quasi-permanent basis, or on the surface facilities. The acoustic cleaning of optical windows can also be applied to wireline logging tools, such as the optical windows used in the Optical Fluid Analyser in Schlumberger's Modular Dynamics Formation Tester tool (described in U.S. Patent No. 4,994,671) or the windows used in the optical probes to monitor multiphase production from hydrocarbon wells, as described in U.S. Patent No. 5,831,743.

FIG. 9B shows a schematic of an ultrasonic transducer 91 and horn 94 used to clean the membrane 961 of an ion selective electrode 96 that could be used to measure the activity of an ionic species in the water produced from a hydrocarbon well. The performance of the membrane 961 is maintained by the cleaning action of the ultrasonic transducer 91 and horn 94, which are in close proximity to the membrane. The ultrasonic cleaning technique can be used to maintain the permeability of membranes used to separate various components from the fluids produced

FIG. 10 shows a schematic of the acoustic sensor used to measure the acoustic transit time ΔT_t through the scale film. This acoustic sensor could be used either downhole or above ground on the surface facilities. Pulsed ultrasound is emitted from an emitting transducer 981 and the reflections are collected by a second receiving transducer 982. The acoustic impedance Z of the scale layer 99 can be estimated by the measured values of the mass W of scale attached to the acoustic horn 97 and ΔT_t . The thickness of scale h attached to the horn is related to W by

According to the invention monitoring scale/deposits removal techniques are provided. The acoustic scale sensor can be used to evaluate the efficiency of an external scale removal treatment process, such as a scale dissolver solution or a

physical scale removal technique. The scale removal treatment can be monitored in real time using the change in the resonant frequency of the transducer and horn. The acoustic scale monitor can therefore be used as part of a scale maintenance service that monitors scale accumulation and evaluates the cleaning/removal process. The maintenance service can be applied to the accumulation of scale both in a producing wellbore or in the surface equipment.

10 According to the invention, fluid composition and pressure effects can be determined. The resonant frequency of the ultrasonic transducer and horn with no deposits attached depends on the composition of the fluid with which it is in contact and its hydrostatic pressure. A change in the composition of the produced fluid or its hydrostatic pressure may therefore obscure the change in resonant frequency due to the accumulation of inorganic or organic deposits. A change in resonant frequency due to a change in fluid properties can be measured using a second matched transducer and horn, which is in close proximity to the scale detector. The second transducer is cleaned frequently to ensure that the horn is always free from inorganic and organic scales and that the changes in its resonant frequency are solely caused by changes in fluid composition and pressure.

25

Surface Modification of Acoustic Horn. An important aspect of a scale/deposits sensor permanently installed in a producing hydrocarbon well or in the surface facilities is that the rate of accumulation of deposits must be the same as that of the region of the wellbore it is monitoring. The composition and morphology of the surface of the tip of the horn should be such as to give the same rate of scale accumulation as the solid surfaces in the close environs of the sensor. The surface of the horn tip should be suitably controlled by the choice of material

and/or coating. The material and coating used to fabricate the horn should be able to withstand repeated sonication.

Size of Transducer and Horn. The size of an ultrasonic
 5 transducer and horn may be a critical issue for the permanent
 placement of such a device for scale/deposits monitoring. The
 size of the transducer and horn are largely determined by the
 desired frequency of operation and the materials use to them.
 High power ultrasonic transducers and horns in the size range 5-
 10 6 cm, which operate in the frequency range 89-113 kHz, have been
 reported by Lal and White. See, Lal, A. and White, R.M.,
 "Silicon microfabricated horns for power ultrasonics", *Sensors
 and Actuators*, **A54**, 542-546 (1996). The acoustic horns were
 microfabricated from silicon wafers.

15

While preferred embodiments of the invention have been
 described, the descriptions and examples are merely illustrative
 and are not intended to limit the present invention.

CLAIMS

What is claimed is:

- 5 1. A deposit monitoring apparatus located above ground level comprising:
 an acoustic device adapted to operate in a resonance mode in a frequency range of 10 kHz to 250 kHz, the device including a monitoring surface directly exposed to fluids
10 prone to causing deposition of material, wherein the deposition of the material on the monitoring surface is monitored by measuring a change in resonance frequency of the acoustic device; and
 a power supply adapted to supply said monitor with
15 electrical energy.
2. The apparatus of claim 1, wherein the acoustic device operates in a longitudinal mode.
- 20 3. The apparatus of claim 2, wherein the acoustic device further comprises a transducer, and a focussing element coupled to the transducer.
- 25 4. The apparatus of claim 3, wherein the focussing element is an acoustic horn.
5. The apparatus of claim 1, wherein the resonance frequency of the acoustic device is in the range of 10 kHz to
30 150 kHz.
6. The apparatus of claim 5 wherein the resonance frequency of the acoustic device is in the range of 50 kHz to
 100 kHz.

15. The sensor of claim 1, wherein the sensor includes an additional sensing system to analyze material deposited on the monitoring surface.

5 16. A deposit monitoring apparatus located above ground level comprising:

a deposit monitor adapted to measure deposition of material on a monitoring surface that is directly exposed to fluids prone to causing deposition of material;

10 a power supply adapted to supply said monitor with electrical energy; and

a deposit removal system in communication with the deposit monitor adapted to at least partially remove the deposition from the monitoring surface, the deposit removal
15 system being in a control loop with said deposit monitor.

17. The apparatus of claim 16 wherein the fluids are primarily fluids produced by a hydrocarbon wellbore.

20 18. The apparatus of claim 16, wherein the monitoring surface is located on or near one of the following devices switches, valves, sleeves, mandrels, risers, subsea pipelines, surface separators and sensors located on surface facilities.

25 19. The apparatus of claim 16 wherein the deposit monitor further comprises an acoustic device adapted to operate in a resonance mode, wherein the deposit monitor measures deposition of the material on the monitoring surface by measuring a change in resonance frequency of the acoustic device.

30 20. The apparatus of claim 19, wherein the acoustic device operates in a longitudinal mode.

25

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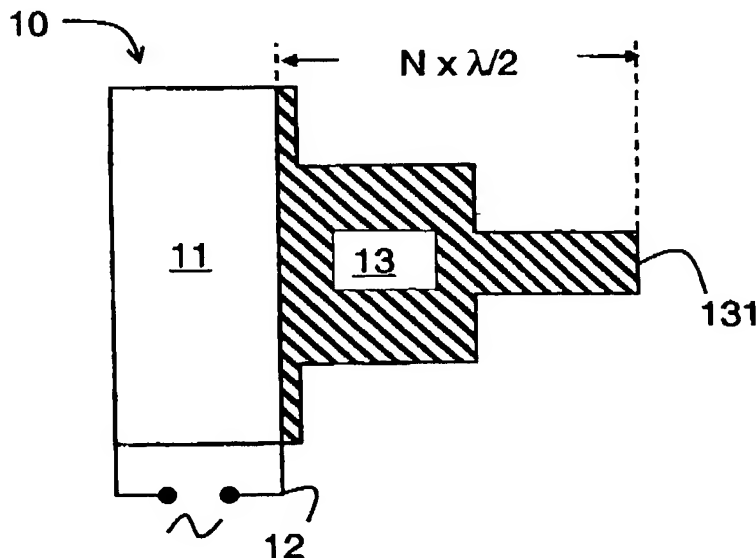
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- (81) **Designated States (national):** AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.
- (84) **Designated States (regional):** ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

[Continued on next page]

(54) Title: DEPOSITION MONITORING SYSTEM



(57) Abstract: Described is an apparatus for detecting and removing deposits from a surface exposed to wellbore fluids. The apparatus can monitor the rate of deposition and subsequently remove the deposited material. The combination of detection apparatus and removal apparatus provides an instrument with self-cleaning operation mode.

WO 01/31329 A1

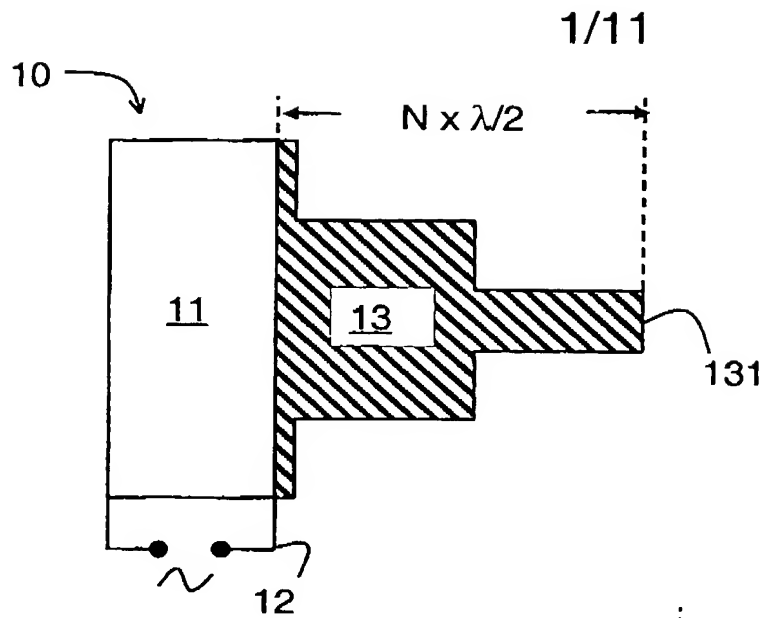


FIG. 1A

FIG. 1B

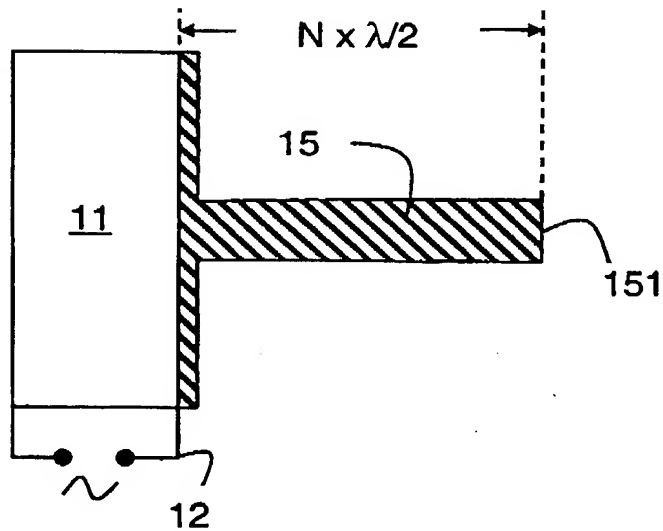
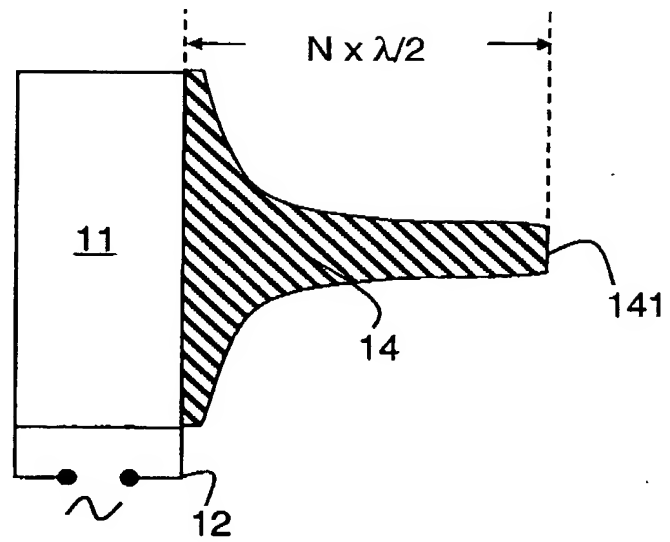


FIG. 1C

2/11

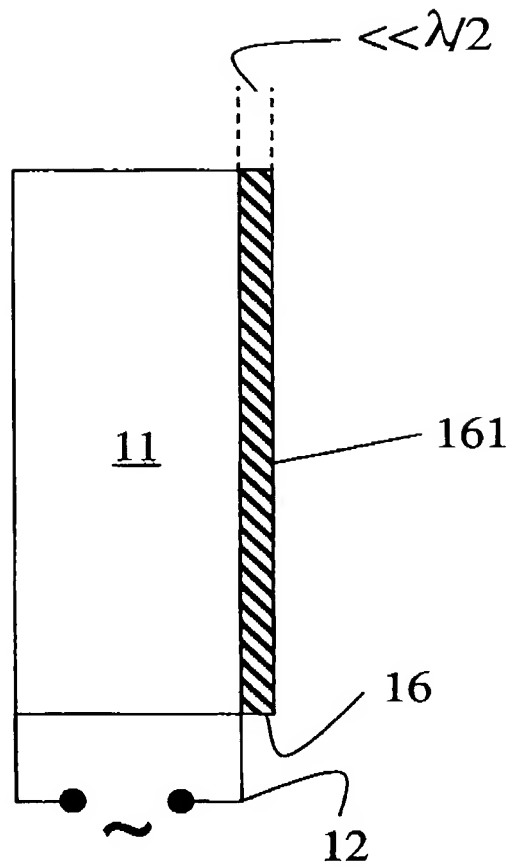
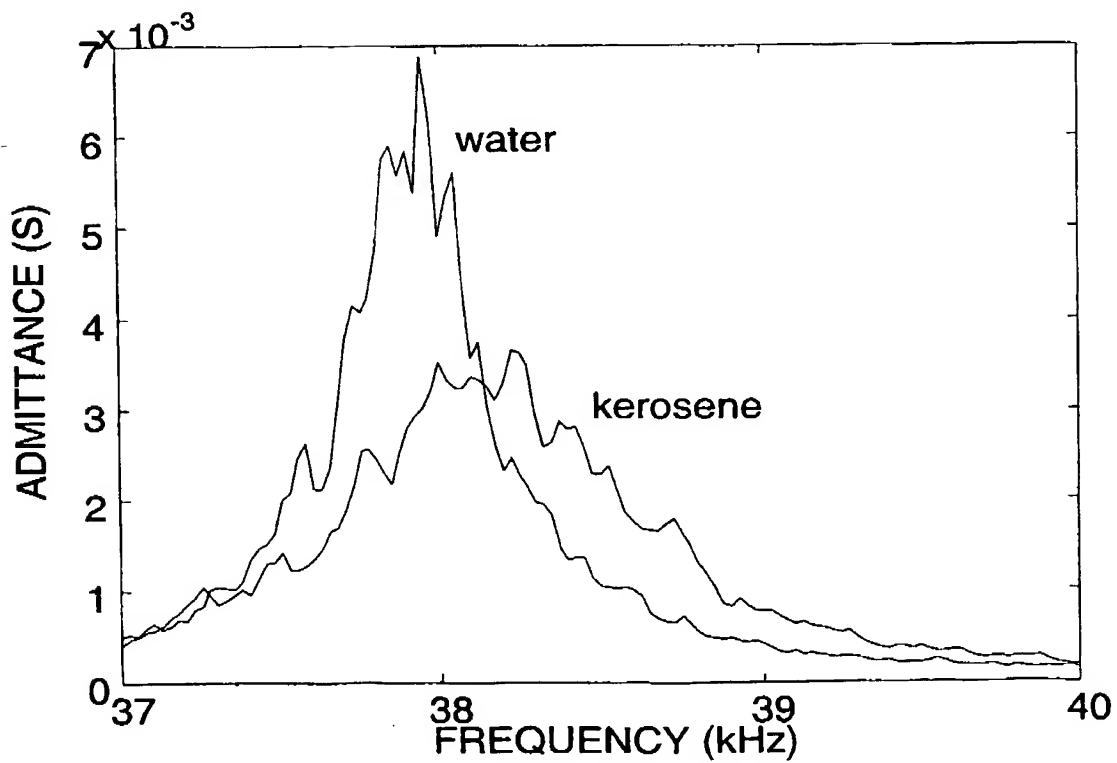
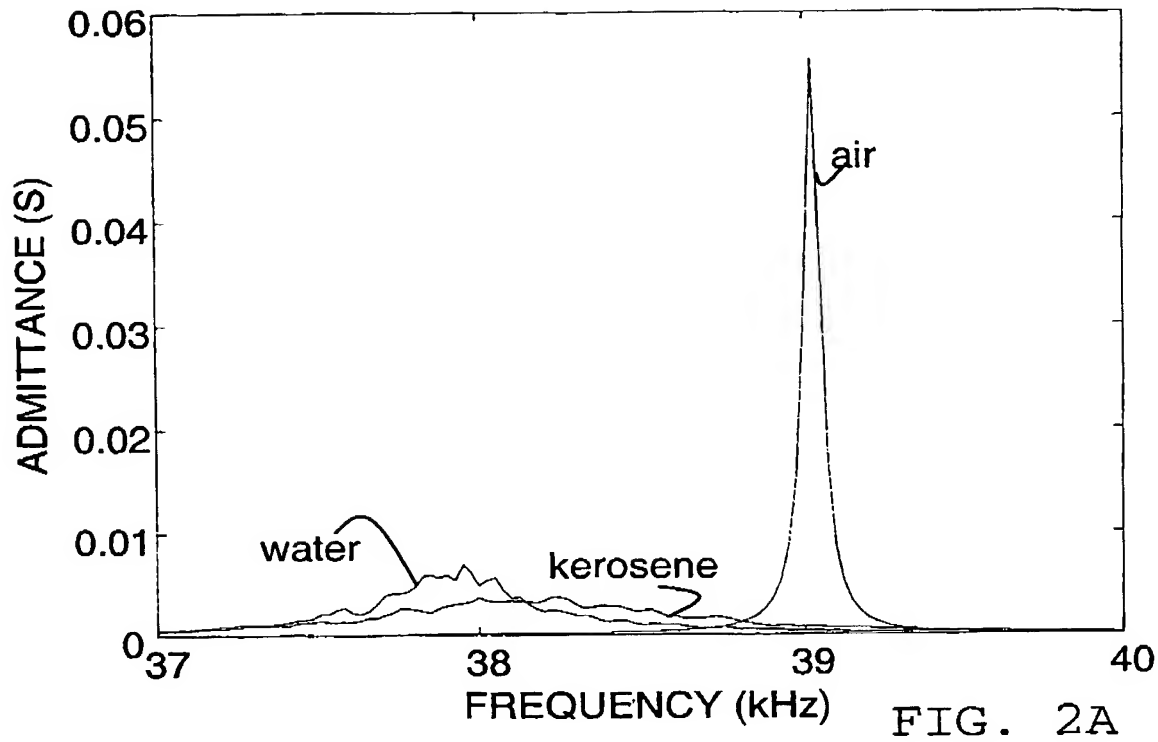


FIG. 1D

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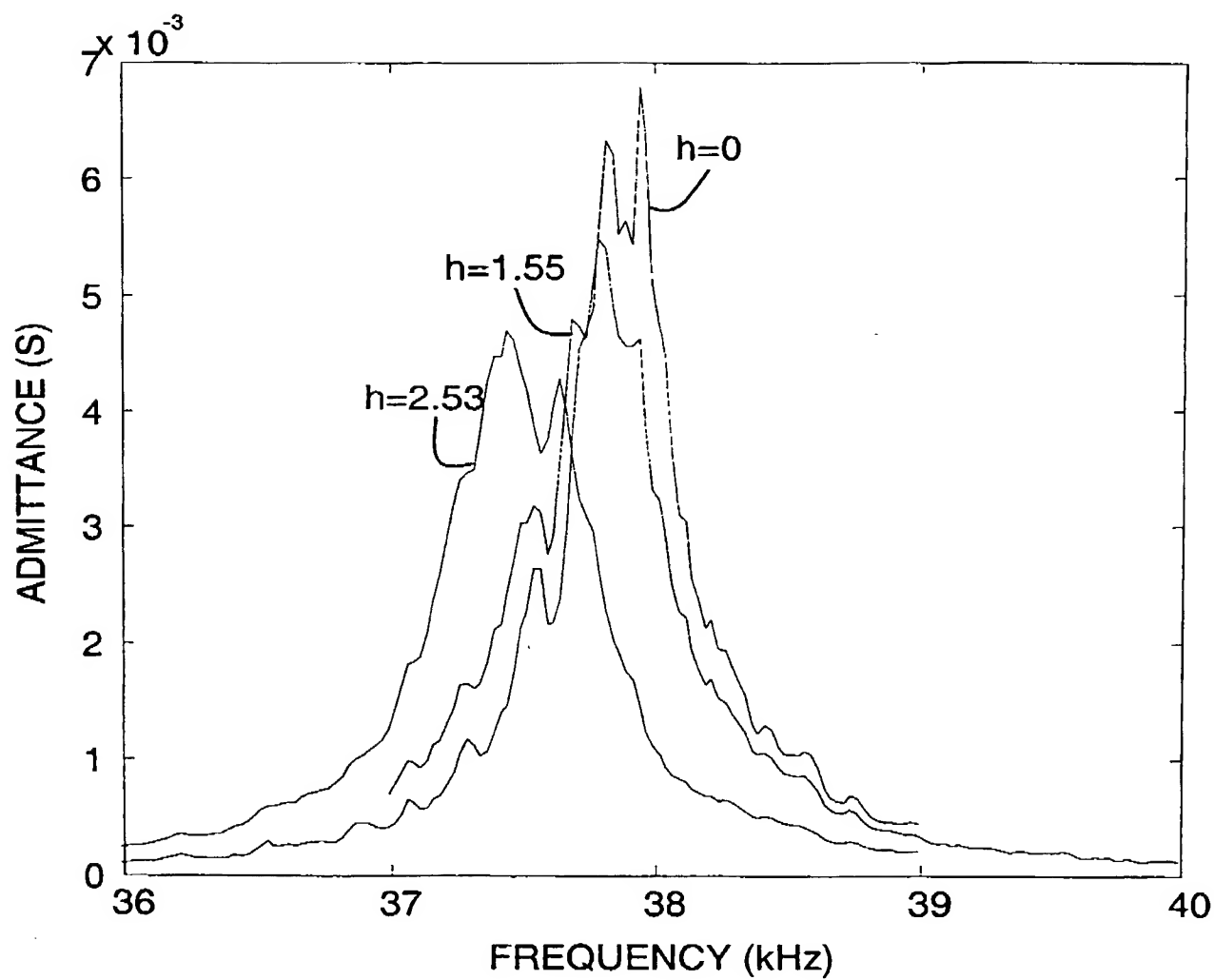


FIG. 4

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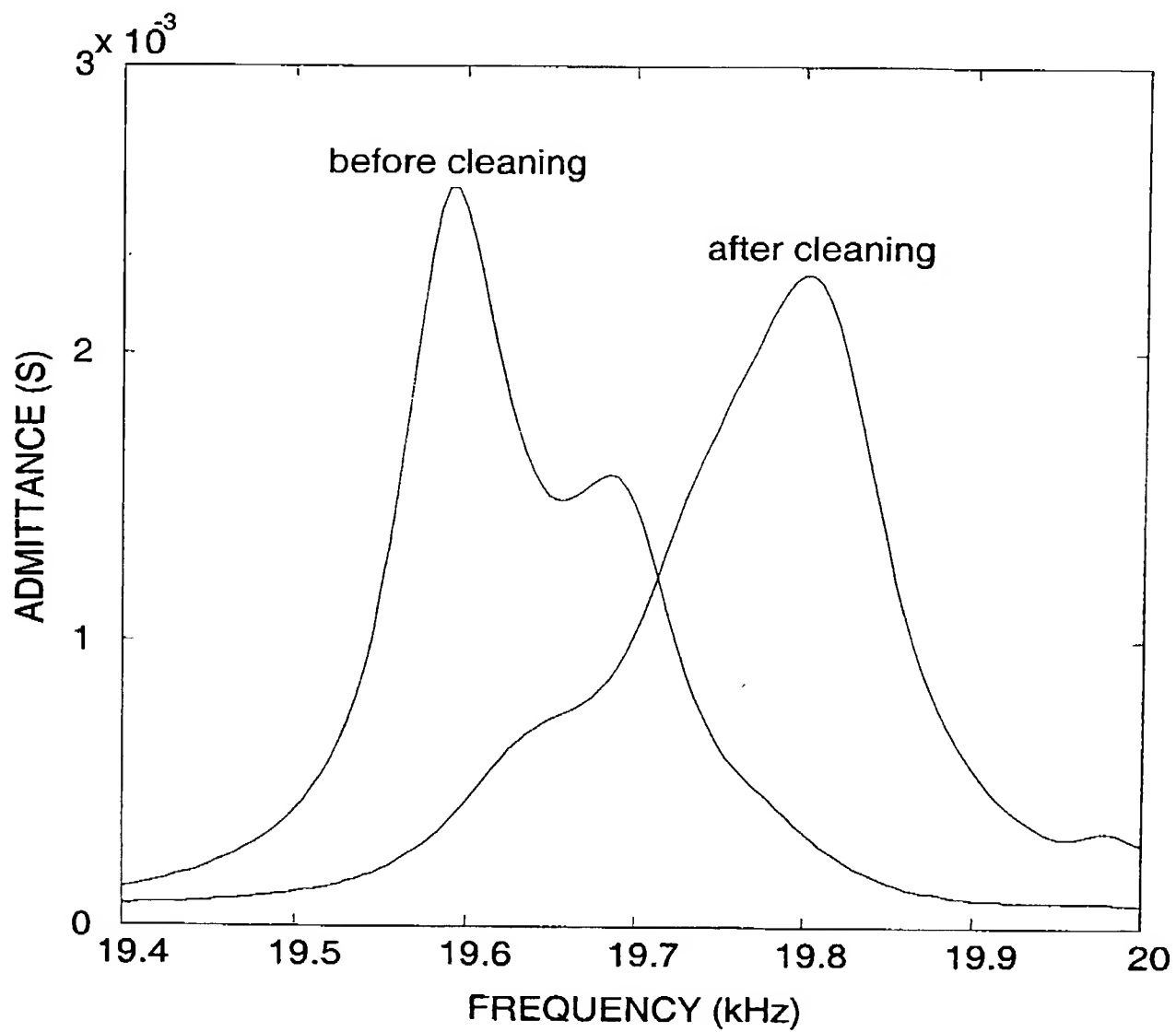


FIG. 5

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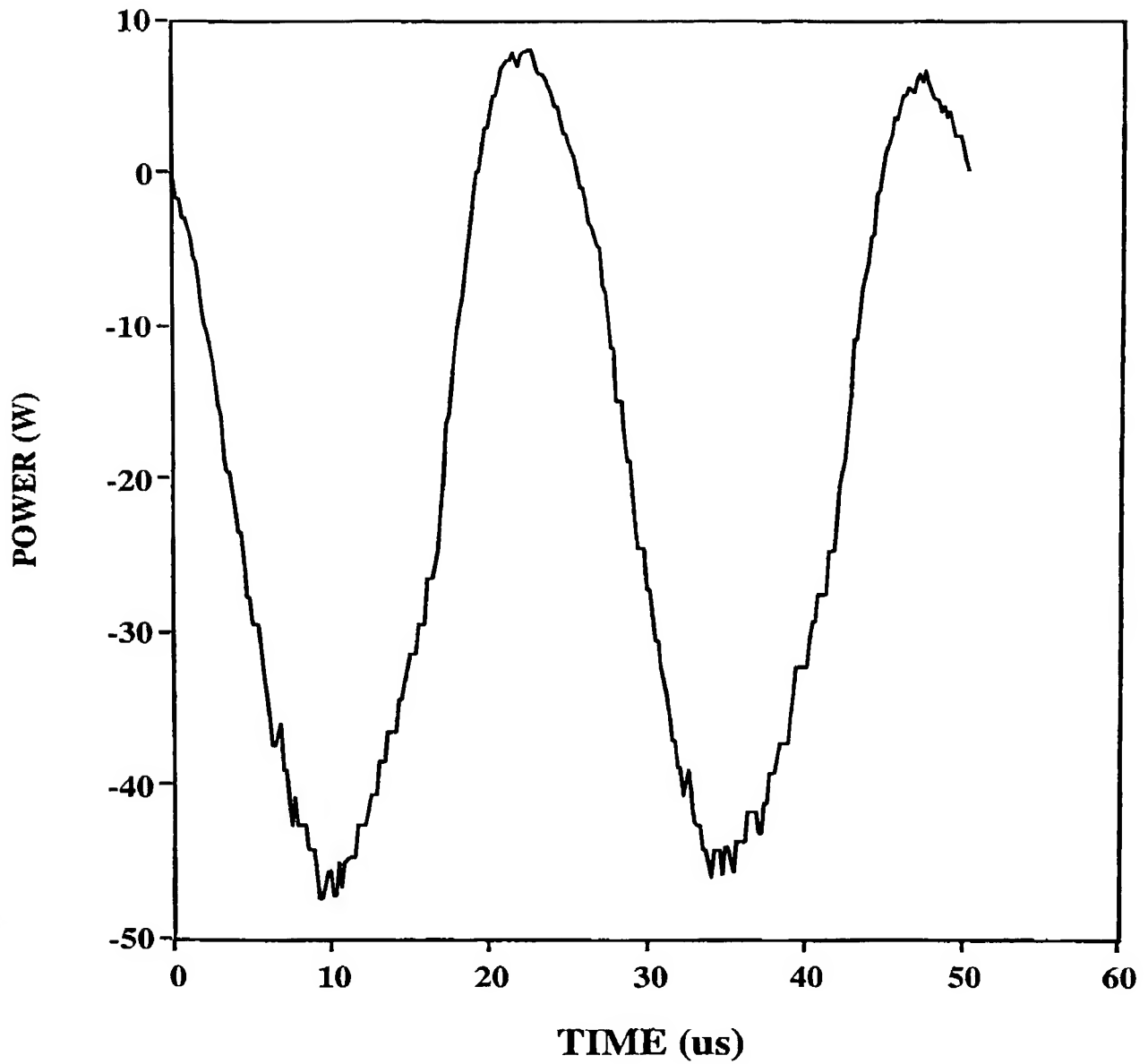


FIG. 6

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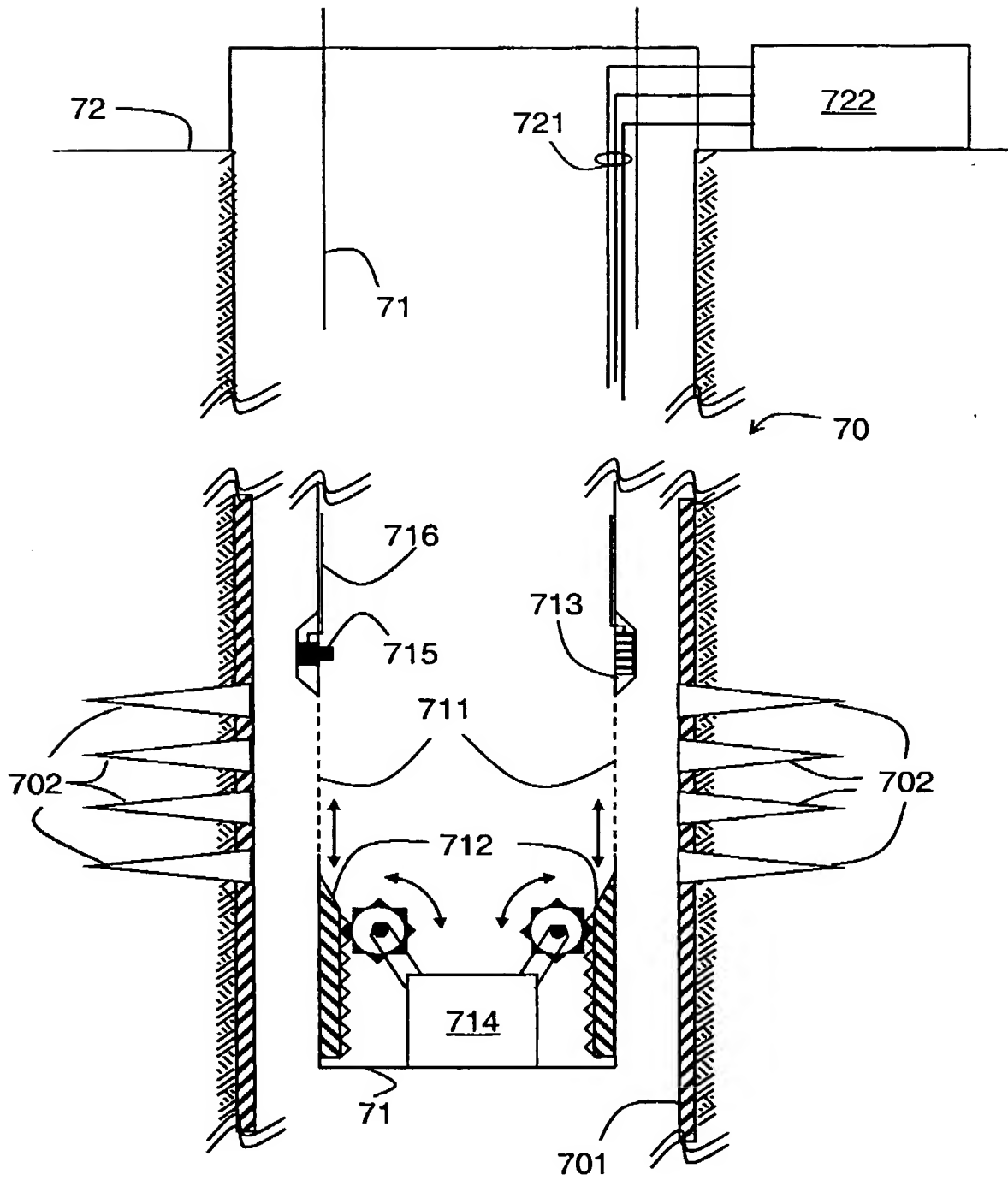


FIG. 7

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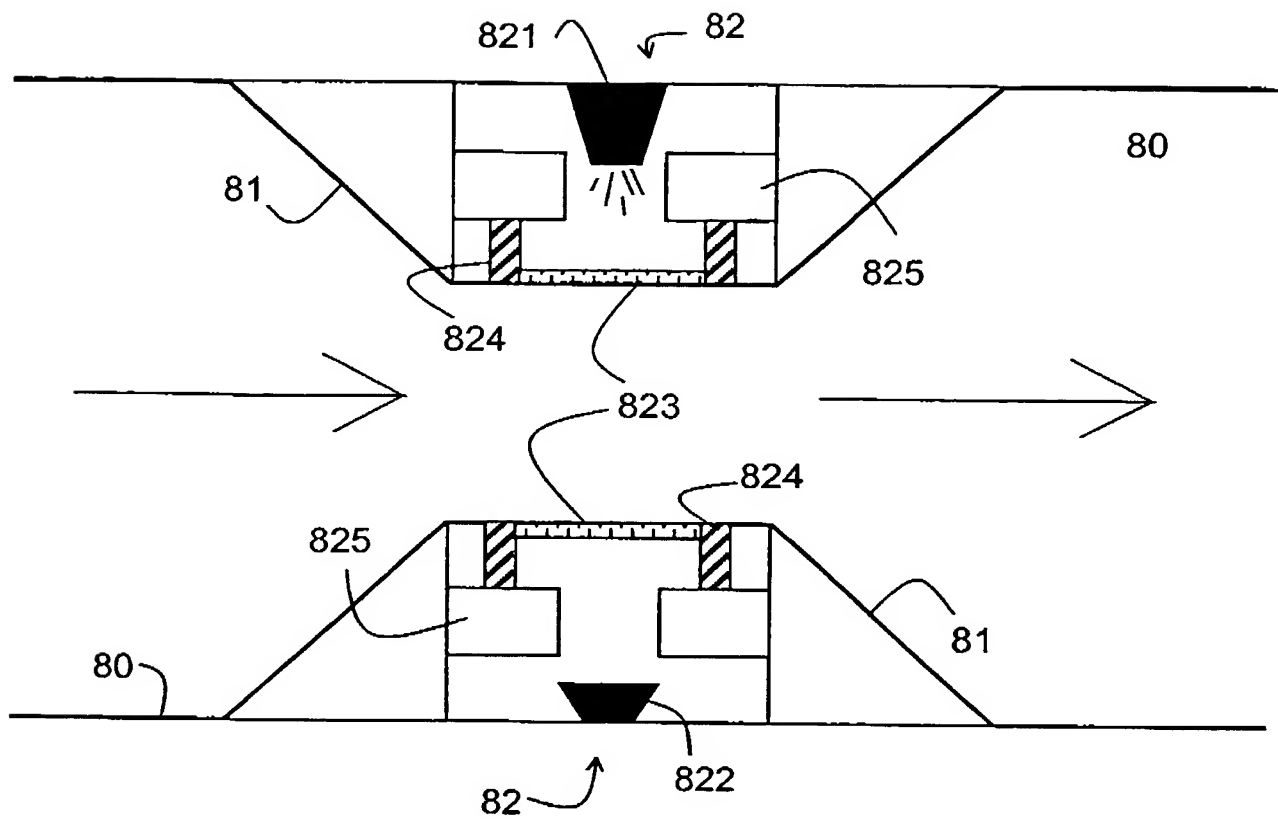


FIG. 8

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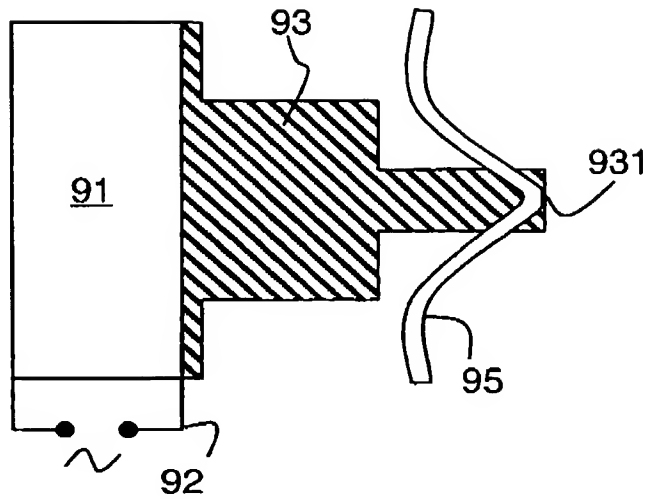


FIG. 9A

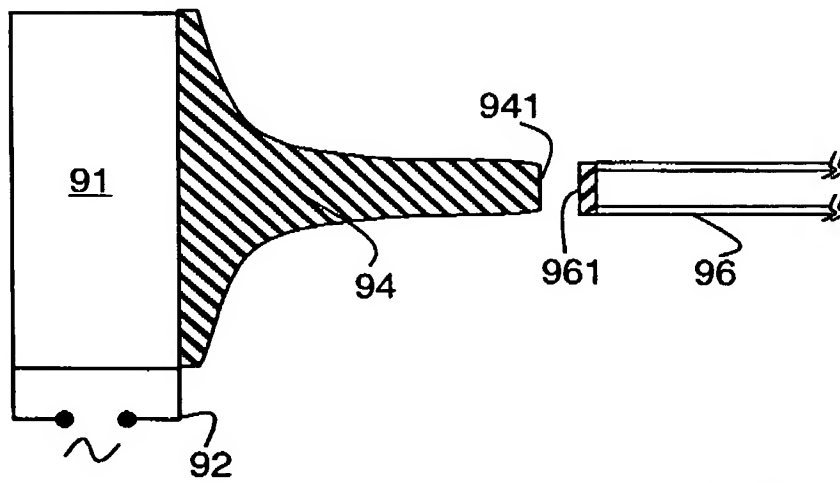


FIG. 9B

11/11

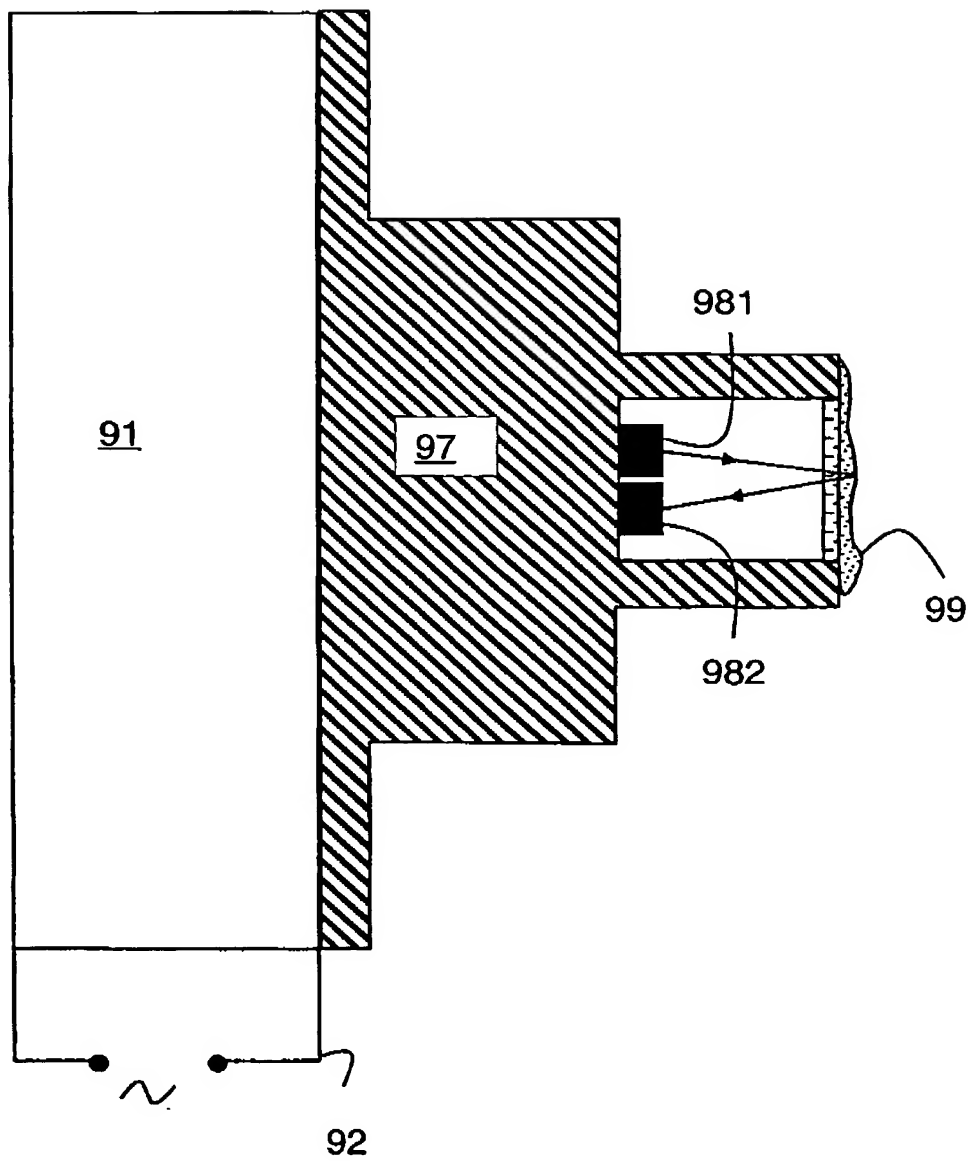


FIG. 10

DECLARATION FOR PATENT APPLICATION AND POWER OF ATTORNEY

As a below named inventor, I/We hereby declare that:

My/Our residence, post office address(s) and citizenship(s) are as stated below next to my/our name(s), and

I/We believe I/We am/are the original, first and sole inventor of the subject matter which is claimed (if only one name is listed below) or an original and first inventor of at least some of the subject matter which is claimed (if plural names are listed below) and for which a patent is sought on the invention entitled

DEPOSITION MONITORING SYSTEM

the specification of which

☐ is attached hereto.

☒ was filed on **26 October 2000**

as PCT International Application No. **PCT/GB00/04129**

and was amended on _____ (if applicable).

I/We hereby state that I/we have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I/We acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

Prior Foreign Application(s)

I/We hereby claim foreign priority benefits under Title 35, United States Code, Section 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application(s) for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Country	Application No.	Filed (d/m/y) (27.10.99)	Issued (d/m/y)	Priority Claimed
Great Britain	9925373.4	27 October 1999		Y <input checked="" type="checkbox"/> N <input type="checkbox"/>
				Y <input type="checkbox"/> N <input type="checkbox"/>

Prior United States Applications

I/We hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I/We acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

Application Serial No.	Filing Date (d/m/y)	Status (Patented, Pending, Abandoned)

John J. Ryberg, 31,134; William B. Batzer, 37,088; William L. Wang, 39,871; and Jody Lynn DeStefanis, 44,653.

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